Developing a Decision Support System using Fuzzy Logic for Sugarcane Supply Cycle Management

Tinsae Berhanu
HiLCoE, Software Engineering Programme, Ethiopia
ztinsae.berhanu@gmail.com

Wondowssen Mulugeta
HiLCoE, Ethiopia
School of Information Science, Addis Ababa University, Ethiopia
wondwossen.mulugeta@aau.edu.et

Abstract

Supply of sugarcane at the right time in the right amount for years to come is pivotal if it is to achieve maximum productivity of commercial sugar from sugar factories. Sugarcane supply cycle is a process that will stabilize the temporal productivity of sugar from sugar factories by supplying the right amount of sugarcane at the right time from the plantations that are owned by the factories.

This planning system is particularly important in the pioneering sugar factories of Ethiopia as the average cane maturity age in most cases elapses beyond a year. An automated sugarcane supply cycle management system, which is the subject of this paper, will eliminate the hideous drudgery of cane supply planning currently in practice and could facilitate the subject matter experts to review multiple sugarcane supply cycle alternatives in a short period of time. This proposed intelligent software application will generate seven sugarcane supply cycle scenarios; one conventional and six in fast track planning methods.

In addition, some of the features of the estimation process are subjective variables where integrating fuzzy logic to the automated system will make the analysis of supply sugarcane management more objective and intelligent. This paper, therefore, tries to come up with a software application that will generate multiple sugarcane supply cycles in two categories, viz., conventional method and fast-track method with the aid of fuzzy logic.

The proposed prototype is satisfactory as per subject matter experts. This is tested by letting them interact with the prototype and generate various sugarcane supply cycles using both conventional and fast track methods. After generating the supply cycles they were able to manage the printable report with little learning curve to the system's user interface.

Keywords: Fuzzy Logic; Sugarcane Supply Cycle; System Automation; Decision Support System

1. Introduction

Sugarcane is the major raw material used by sugar factories in sugar production. Unlike many other countries involved in the manufacturing of sugar, the Ethiopian sugar industry adopted the nucleus estate sugarcane growing modality whereby both the sugar factory and the sugarcane plantation operate under single management structure [1].

Under nucleus estate cane development modality, the sugar mill is required to develop its own integrated cane plantation that is sufficient to meet the annual uninterrupted cane crushing capacity of the mill [1]. With the help of carefully designed cane supply planning, the sugarcane to be supplied to the mill on a daily basis is required to meet the desired optimum variables in terms of age, varietal composition, cuttings, etc.

Planning the cane cycle program and its management has persisted as major challenge in all sugarcane growing countries in general and in Ethiopian sugar factories in particular. This is attributed to the inclusion of a number of variables in the planning process that are governed by natural phenomena which are beyond the direct control of a human. It is to be noted that sugar factories are established in different project areas with variable environmental settings that have direct influence on these factors.

In Ethiopian sugar factories, the cane cycle planning process and its management is carried out manually by subject matter experts, reported to be very few in number as the knowledge is gained through long years of work experience that is passed from one person to the other rather than formal training [1]. The planning process is highly drudgery as the work involves huge iteration work, and, as a matter of fact, highly disliked by most staff involved in the process [1].

Currently, the process of developing sugarcane supply cycle is done using MS Excel application. The problem with this process is that it costs a lot of time and energy to come up with the proper supply cycle due to a lot of variables to be considered in the process making it highly prone to error. In addition, usually, one sugarcane supply cycle is not sufficient for plantations.

The aim of this paper is, therefore, to develop a robust software that can assist subject matter experts to develop alternative scenarios in cane supply planning and enable them to select the optimum scenario for implementation. The outcome from this work will be of use for managing the cane supply plan.

Two distinct phases are identified while formulating cane supply plan for a factory [1]. These are (i) initial development (establishment) phase plan and (ii) steady state operation phase plan. With respect to development rate, basically two alternative systems are available [1], namely:

- *Conventional system*: which dictates the development rate to be according to the annual rotation area. Annual rotation area is area to be planted regularly every year during steady state operation phase.
- *Fast track system*: where the allowed development rate is well beyond the annual rotation area, and naturally a number of scenarios meeting this criterion could be formulated. This condition makes it very difficult to formulate the possible supply cycles even with a computer system.

The controlling point will be how closely the long-term cane supply plan in terms of the quantity of cane delivered to the factory on daily, monthly and annual basis matches with the required design capacity of the factory [1]. However, among the possible scenarios, identifying the optimum development rate for the establishment phase planting has been a problem for long and requires human assistance in addition to an automated system that helps to investigate between the various available scenarios within a limited period of time.

Fuzzy logic, in this regard, can deal with information arising from computational perception and cognition, that is, uncertain, imprecise, vague, partially true, or without sharp boundaries [3]. Fuzzy logic allows for the inclusion of vague human assessments in computing problems, where it also provides an effective means for conflict resolution of multiple criteria and better assessment of options [3]. Therefore, the use of fuzzy logic in sugarcane supply cycle planning automation to facilitate decision-making is a wise endeavor.

This paper tries to develop a cane supply planning software prototype that has the capacity to forecast the various cane supply cycle options with change of project parameters in accordance to the characteristics of the project location. Hence, the following research questions are formulated.

- How to design and implement a software to manipulate sugarcane supply planning data?
- How could fuzzy logic model be incorporated in the development of the proposed system?

2. Related Work

The biggest challenge in developing a sugar cane supply cycle plan is the complexity resulted from handful of variables. These, ever unstable variables, make the supply cycle plan difficult to be suitable for acceptable operation. Sugarcane supply cycles in the world differ in their nature mainly due to the fact that they can be greatly affected by managerial decisions as much as the natural phenomena.

As the requirements elicited from the subject matter experts show, quite a number of inputs that are constant parameters to a specific factory are required to formulate the cane supply planning [2]. These parameters are mainly determined with the help of an in-depth study and analysis of the natural resource base of the specific area where the envisaged sugar project is located. Then, the results of the resource base will be used to formulate detail project report in which all project parameters are determined.

As argued in [2], the elements of the natural resource base that need to be studied are:

- The land resource of the project area – soil type, land suitability and slope class;
- Climate - long years records of the major climatic variables (temperature, rainfall, potential evapo-transpiration, wind run, relative humidity, length of sun shine hours, etc); and
- Hydrology of the area.

It is to be expected that the characteristics of the natural resource base is highly influenced by geographic locations thus exhibits spatial variability. Table 1 shows the list of project parameters determined by detail study and inputs to be used in formulating cane supply planning and management which are used in the proposed system.

Table 1: Expected Inputs

No.	*Input/Parameter*	*Unit*	*Source*
1.	Factory milling capacity	Ton cane per day (TCD)	Detail project report (DPR)
2.	Annual milling days	days	Resource base study
3.	Cropping pattern	Number of ratoons	Resource base study
4.	Harvest/maturity age	months	Detail project report
5.	Average Cane yield	Ton/ha	Detail project report
6.	Commercial cane area (CC)	ha	Detail project report
7.	Seed cane area (SC)	ha	Detail project report
8.	Initial seed cane area	ha	Detail project report
9.	Total plantation area	ha	Detail project report
10.	Length of one occupation period	year	Detail project report
11.	Harvest proportion between 1RS and 2RS cane	%	Detail project report

Two step planning is involved in preparing this initial stage plan, namely “the cropping pattern plan” and “plantation development and cane production projection plan” [6]. The input for preparing this plan is mainly generated from Resource Base Study Report and Detail Project Report carried out at the time of project feasibility study.

The choice of a well suited cropping pattern is of primordial importance to ensure a regular cane and sugar production, a constant juice quality and a seamless management [4, 5]. In the current trend of producing sugarcane supply cycle, as discussed above, the following terminologies are directly used in the formulation of cane supply cycle:

- *Conventional*: in short, this method is dependent on annual rotation area. For a specific environment where the plantation is placed, there is only one kind of conventional sugarcane supply cycle method. Using the ratio provided by the user on initial seed cane and commercial cane the system will provide the amount of area that will be planted starting from the first year until plantation capacity is met. Just before the end of virgin land planting, depending on the average month of cutting variety, it starts replanting to avoid down time of the factory. According to the planted cane amount, harvesting starts at the third year when the commercial cane is mature enough to produce the expected amount of sugar. Every year, that amount of developed area is determined by Annual rotation area. Depending on the plan on how many ratoon the cane is supposed to last, the first cut will be the first ratoon for next year which will vary in the yield expected. Thus, there will be a variation in the cutting amount.

- *Fast track*: unlike the conventional method, this method can be varied according to the business statues, resource capability and feasibility against the environmental demands. In this method, everything is similar to the procedure used in conventional method except that the annual developed area is not determined by annual rotation area instead it is affected by external factors. Fast track method usually varies by increasing the annually developed area by some percentage. This variations achieved in the process are represented as Fast-Track-One, Fast-Track-Two, Fast-Track-Three, etc.

The main difference between the two methods is that conventional method uses annual rotation area as annual developed area and fast track method uses different external factors of annual developed area to guide the generation of sugarcane supply cycle.

The differences between various fast track methods depend on the business needs of stakeholders. Which means, a faster factory mill has to meet its designed capacity, annual developed area will be annual rotation area plus some percent of the annual rotation area. Usually, adding more than 30% of annual rotation area is not feasible according to the subject matter experts [2].

A research done on Vietnamese farmers decision-making simulation by using fuzzy logic is the most related work found for review. The objective of this paper [2] is to explore the effect of farmers' family motivation on farm diversification and integration using a fuzzy logic model simulating their decision making. Even though the research uses fuzzy logic and agricultural decision-making simulation, it is very difficult to directly relate it with sugarcane supply cycle.

Another work on decision support system [7] presents a detailed framework, conceptual design and prototype of a decision support system which can be used to aid business executives in deciding the appropriate e-business models to use. The design is based on the ideas and concepts of fuzzy logic theory and fuzzy expert systems. The proposed system solves important challenges such as the use of linguistic terms to capture the executives' assessments of the key business measures.

These related works enlighten us the possibility and success of applying fuzzy logic in business area field with much uncertainty and subjective judgments.

3. The Proposed Solution

3.1 Architectural Design

The architectural design (shown in Figure 1) is the high level description of the software application developed. A layered architecture is a very clean architecture for applications that tend to be messy during the development process. It is an appealing option because of the ability it presents to decouple sophisticated procedures in a way the development team can test different related modules without disrupting other modules.

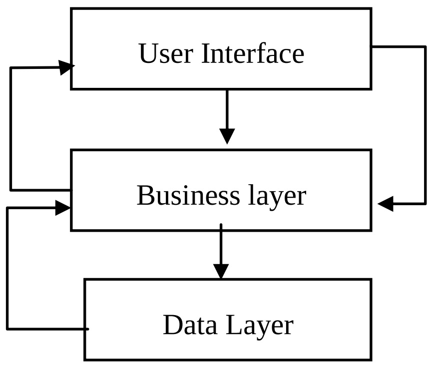

Figure 1: Architectural Design

3.2 Fuzzy Logic Model

Fakhry [7] proposed a decision support framework based on Hayes and Finnegan and the results of Fuzzy Logic Theory and systems by Zadeh in 1965 [8]. Fuzzy logic joins language and human intelligence together using the mathematics of fuzzy membership functions and provides a formal framework to represent and reason with vague, uncertain, and linguistic terms. Using this understanding of fuzzy logic model, the proposed flow of function actions are summarized in Table 4 and described in detail as follows.

a. Linguistic Variables and Terms

In this paper, fuzzy logic model has been used for the generation of fast track method sugarcane supply cycle. Subsequently, developing a linguistics resembling to the terms the professionals have been using to communicate is important for the interface in generating supply cycle. We have come up with these terminologies in consultation with the domain experts, which are presented in Table 2.

Table 2: Linguistics

Supply cycle	*level*
Fast track one	Low
Fast track one	High
Fast track two	Low
Fast track two	High
Fast track three	Low
Fast track three	High

b. Membership Functions

Membership function deals with the association of the linguistics terms with crisp range values. To come up with this numeric values, the subject matter experts have been consulted.

Table 3: Membership Function

Linguistics	*% of annual rotation area*
Fast track one, low	$0<x<5$
Fast track one, high	$5<x<13$
Fast track two, low	$13<x<15$
Fast track two, high	$15<x<23$
Fast track three, low	$23<x<25$
Fast track three, high	$25<x<30$

c. Rule Base

1. If fast track one and low then 5% of annual rotation area is added to annual rotation area.
2. If fast track one and high then 13% of annual rotation area is added to annual rotation area.
3. If fast track two and low then 15% of annual rotation area is added to annual rotation area.
4. If fast track two and high then 23% of annual rotation area is added to annual rotation area.
5. If fast track three and low then 25% of annual rotation area is added to annual rotation area.
6. If fast track three and high then 30% of annual rotation area is added to annual rotation area.

Using the membership functions (parameters and rules) shown in Table 3, the generation of fast track development method part will be executed using the Java code and will be able to generate sugarcane supply cycle.

d. Defuzzification

Defuzzifiaction is the process of using the numeric values and producing the final supply cycle result. Hence, after the process passes the fuzzy rule, it will generate a new fast track method sugarcane supply cycle with the newly acquired value of annual developed area.

Table 4: Functions of the Fuzzy Logic Model

Fuzzyfication	*Fuzzy rule*	*Defuzzification*
▪ Collects linguistic values ▪ Changes into numeric value	▪ Applies fuzzy rule and sends value	▪ Generates sugarcane supply cycle according to the value passed by the fuzzy rule

3.3 Sample User Interface

The user interface appears just after a person is logged in as a professional. It helps the user to fill prerequisite data that will be used to generate sugarcane supply cycle.

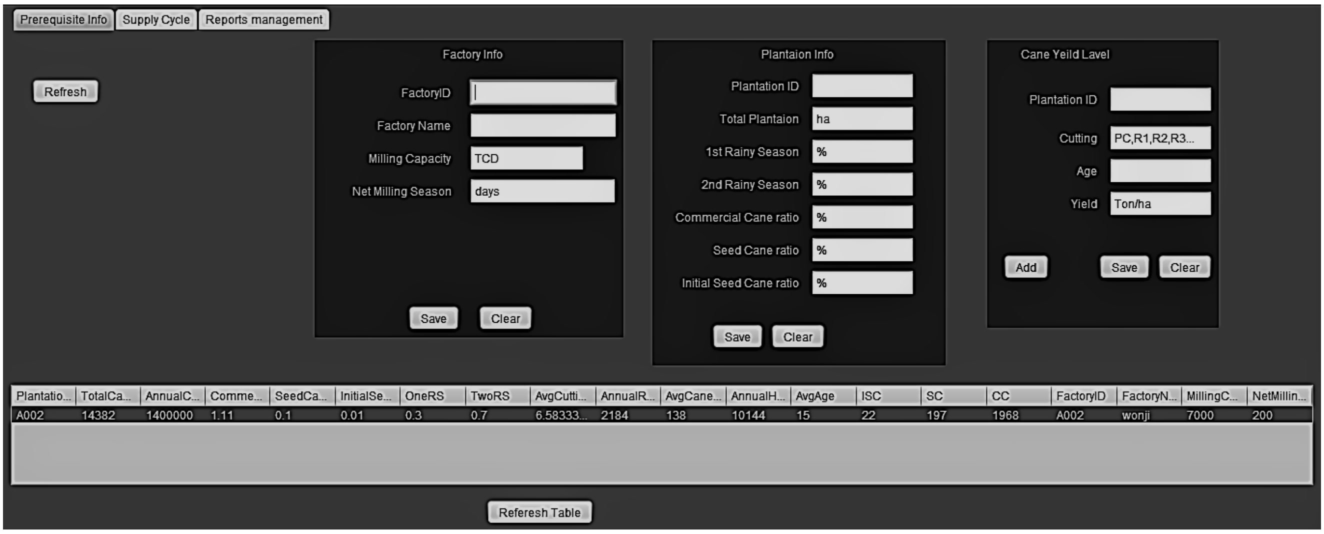

Figure 2: Prerequisite Info Page

Figure 3 shows the page that is used to generate the sugarcane supply cycle and tabular report.

This report is generated based on the data that was provided previously using the screen shown in Figure 2. It also provides the capability to choose between the two types of methods that are used to generate a sugarcane supply cycle. It also provides the option to choose the level of fast track method.

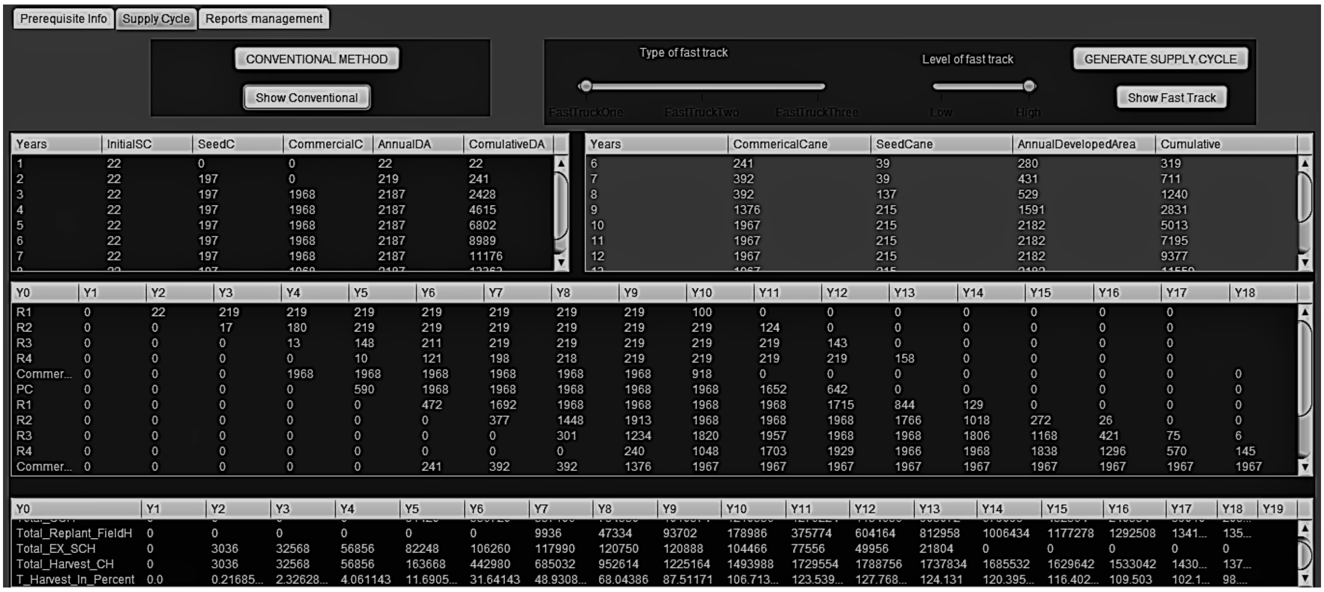

Figure 3: Supply Cycle Management

4. Discussion

Fuzzy logic has been most useful in generating fast track method sugarcane supply cycle. It has been used to determine the different types of fast track supply cycles with specific plantation area information but varying the annual developed area of plantation. In the process of conducting this research, the intent was to incorporate fuzzy logic to the system in place so that it could be more intelligent and reduce the hideous drudgery the subject matter experts go through. It is found that most current professionals who are familiar with the concept of sugarcane supply cycle use manual and complicated MS Excel file to do their job. This is the main motivation to design and develop such software which employs fuzzy logic to address the challenge of uncertainty.

The prototype can generate sugarcane supply cycle and has an integrated fuzzy logic for the generation of a fast track method supply cycle generation. As it was mentioned above, there are two main parts of cane supply cycle management, establishment state and steady state management. From this two cycle managements, we have used establishment part of the management in this research.. In order to come up with the cane supply cycle there are two distinct methods, conventional and fast track methods. We have developed the prototype to accommodate both methods and report a printable result. While generating the supply cycle the system calculates the yearly cutting schedule by comparing with the given annual yield value, the yearly cutting schedules are generated according to the cutting yield level, average age of PC + Ratoon, design capacity of the mill, etc.

Evidently, fuzzy logic model applicability is for the fast track method cane supply cycle. In the generation of a fast track method the user only has to select the type of fast track method (Fast track one, two, or three) and the ceiling of the selected fast track method. The fuzzy logic model will convert this human understandable linguistic but not computable values of information to computable forms and generate the suitable cycle.

5. Conclusion and Future Work

In order to construct a feasible linguistics for the fuzzy logic as well as to come up with the crisp values of those linguistic values, subject matter experts' opinion was pivotal. Nevertheless the testers of the prototype were those people who provided the information needed. The results from the tests conducted were promising. Testing is not a one-time event; it had to be an iterative process to validate the usability of the prototype. In the testing process, there were two domain experts involved who were closely working in this research. After using the application in the presence of the developer, their perception towards the system was found to be satisfactory. Although the prototype can generate seven cycles, they were very much interested in the application of fuzzy logic. Especially in the process of finding the most optimum cane supply cycle and widening the scope of the application are the most essential ideas that could improve the acceptability of the system. Subsequently, usability of the prototype could be improved by making it more responsive to the user's action.

Concluding from the result gathered from the reaction of the subject matter experts it has been an irrepressible fact that fuzzy logic incorporated software application for sugar cane supply cycle is a powerful artifact that most definitely will support the process of developing a profitable sugar factory.

For future there are two main directions that could be exploited:

- to improve establishment phase by proposing a way to get the optimum supply cycle plan, and
- to make the prototype complete and fulfledged with the steady state operation of the supply cycle.

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